Lateral Mixing

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LONG-TERM GOALS

I seek to understand the processes controlling lateral mixing in the ocean, particularly at the submesoscale, i.e. 100m-20km.

OBJECTIVES

Existing high resolution regional models typically resolve the mean vertical structure of the upper ocean boundary layer. Physically-based parameterizations of vertical fluxes make it possible to account for subgrid mixing at length scales smaller than the layer depth, but no specialized parameterization is used to represent the dynamics of horizontal mixing below the O(1)*km* - O(10)*km* resolution scale. We aim to determine the physical limitations of subgrid parameterization on these scales. These projects address the following questions:

- What physics govern horizontal and vertical mixing in the presence of horizontal variability on the 1-10 km scale?
- What is the relative importance of horizontal and vertical mixing in determining the structure of the boundary layer?
- What physics should be included to improve parameterizations?

APPROACH

During AESOP, Lee and D'Asaro pioneered an innovative approach to measuring submesoscale structure in strong fronts. An adaptive measurement program employed acoustically-tracked, neutrally buoyant Lagrangian floats and a towed, undulating profiler to investigate the relative importance of vertical and horizontal mixing in governing boundary layer structure in the presence of O(1 km) scale horizontal variability. Remotely sensed sea surface temperature and ocean color, combined with rapid, high-resolution towed surveys and model results guide float deployments to key locations within fronts. Synoptic, high-resolution surveys followed Lagrangian float drifts to characterize three-dimensional variability within the span of a model grid points. Acoustic tracking allowed towed surveys to follow floats and geolocated all observational assets for later analysis. Measurements characterized boundary layer turbulence and facilitated detailed separation of vertical and horizontal

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE
30 SEP 2011

2. REPORT TYPE

3. DATES COVERED
00-00-2011 to 00-00-2011

4. TITLE AND SUBTITLE
Lateral Mixing

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
University of Washington,Applied Physics Lab,1013 NE 40th St,Seattle,WA,98105

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

processes.   These measurements were specifically designed to allow direct comparison with Large Eddy Simulations of the measurements by Ramsey Harcourt and thus have direct application to assessing regional model subgrid parameterizations.

This project funds final analysis of 2006 and 2007 AESOP data, the 2011 Lateral Mixing experiment and and fund preparations for 2012 Lateral Mixing experiment.

WORK COMPLETED

A manuscript describing the 2007 AESOP data was published in Science Magazine as a featured research article along with an introduction by Raffaele Ferrari. The analysis of the 2006 AESOP data is complete and a paper is in preparation. Together, these studies demonstrate the presence of symmetric instability in wind-forced frontal boundary layers as has been predicted by theory.

I participated in the first experimental program of the Lateral Mixing DRI from June 1-22, 2011. Three ships, the *R.V. Oceanus*, *R.V. Endeavor* and *R.V. Cape Hatteras* worked off Cape Hatteras to survey the circulation and mixing near patches of dye that were deployed in the upper thermocline. My primary role in this program was to help coordinate the diverse experimental activities into a coherent whole and place the dye injections in physically sensible locations. Toward this goal, Ramsey Harcourt first established a data system which collected data from all three ships at a server at APL/UW and redistributed it back to the ships so that all would have access to all of the data. Routine SST, AVISO and model output products were produced on a uniform scale and format as matlab files, figures and .kml files for use with Google Earth. Second, Andrey Shcherbina, on the *Oceanus*, was tasked to produce daily analyses of the ocean circulation based on this data. I used these products as the basis for daily scientific meetings during which I briefed the PIs on the local oceanographic situation. This information was used to plan the next few days' measurements.

In addition, I deployed two Lagrangian floats in the dye patches programmed to track the isopycnal on which the dye was injected. The floats were tracked acoustically from the *Cape Hatteras* as it surveyed the dye. One of these floats was equipped with a 'racetrack', shown in Fig. 1, which rapidly and repeatedly profiled temperature, pressure and dye concentration.

RESULTS

The experimental plans for the LATMIX-I experiment required two phases: first sampling in a 'quiet' ocean region dominated by internal waves with weak geostrophic strain and then in a 'moderate' region with a geostrophic strain not much larger than a few e-foldings per day. The quiet region was relatively easy to find based on AVISO maps and verified by a day of ship ADCP surveys.   The second region was more challenging.   A set of coordinated and telescoping ship ADCP surveys revealed a nearly classic stagnation point with a strain of about 0.8 per day. The dye was injected just north of this point and strained northward over the next few days into a streak several tens of kilometers long while spreading laterally. This was strong enough to contrast with the first low-strain case, but weak enough not to overly spread the experimental resources. I consider this placement to be a major success of the experiment.

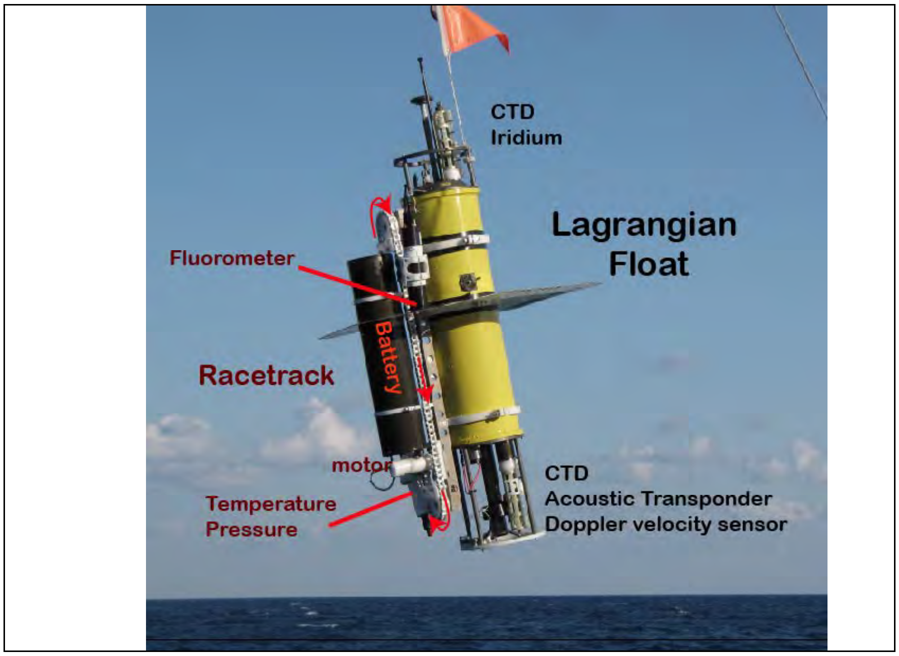

Figure 1. Lagrangian float with 'racetrack' attached. Float measured temperature and salinity on the top and bottom and used these to maintain itself on the same isopycnal as the dye. The racetrack repeatedly profiled dye concentration and temperature along an ~1.2 m long line on the side of the float.

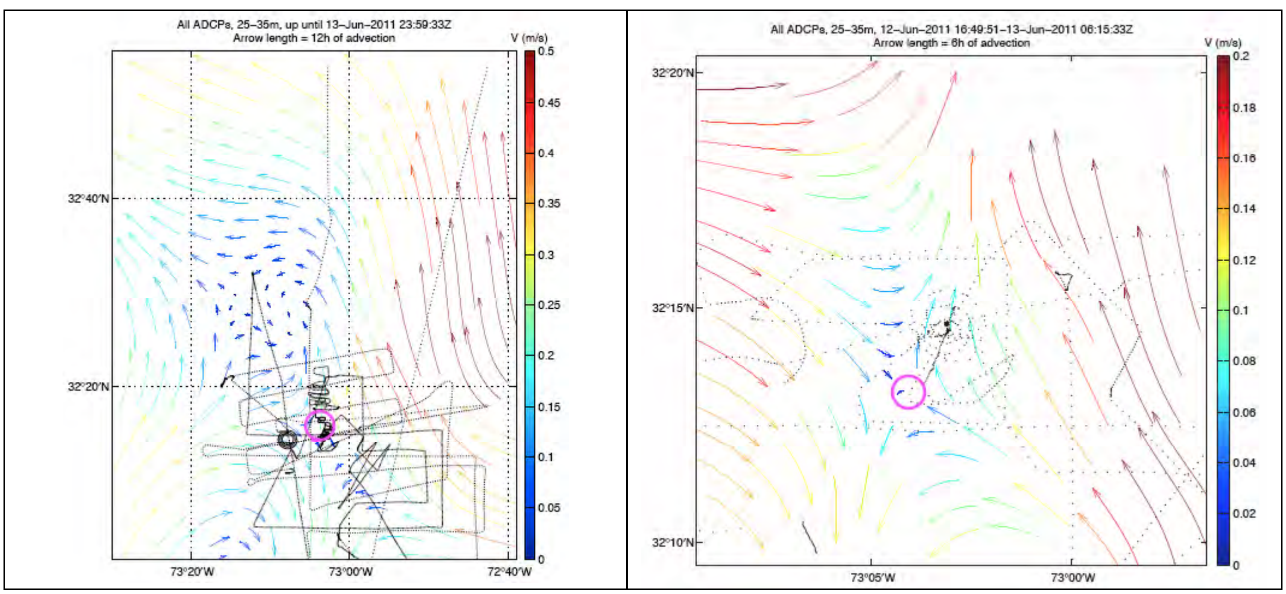

Figure 2. Objective maps of near-surface current on a 60 nm scale (left) and 10 nm scale (right) show a classic stagnation point at the magneta circle, with currents converging from the northwest and southeast, and diverging to the northeast and southwest.

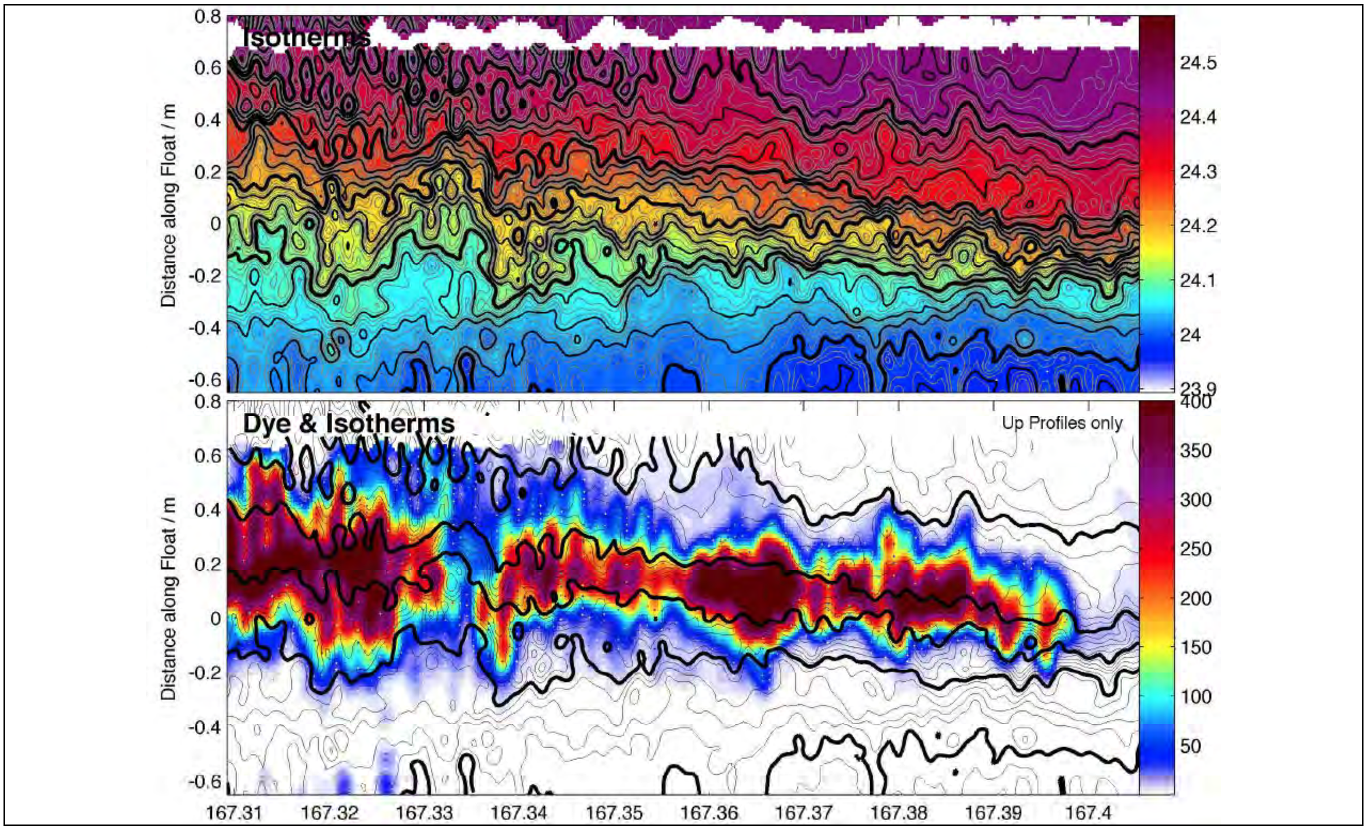

Figure 3. Segment of Lagrangian float data. Top panel shows isotherms from the profling temperature sensor colored by temperature. Bottom panel shows dye concentration in bbp colored with isotherms overlaid.

Sample data from the high resolution float data (Figure 3) shows the dye concentrated between two isotherms in a layer approximately 0.3 m apart. The isotherms show numerous high frequency internal waves as expected. Further analysis will be required to determine if the many small overturns are real or an instrumental artifact. More likely, the most useful information will come from the evolution of the spectra of vertical strain. The dye concentration is quite patchy, unfortunately but most likely due to strong mixing caused by the injection system and not small-scale ocean mixing.

IMPACT/APPLICATIONS

Our results suggest that the theoretical predictions of a boundary layer dominated by symmettric instability in wind-forced fronts are mostly correct.

The success of the LATMIX-I experiment shows the increasing ability of ONR-funding academic researchers to work together in a coordinated team to tackle difficult oceanographic measurement tasks.

PUBLICATIONS

Enhanced Turbulence and Energy Dissipation at Ocean Fronts, Eric D'Asaro, Craig Lee, Luc Rainville, Ramsey Harcourt, and Leif Thomas, **Science**, 15 April 2011: 332 (6027), 318-322

HONORS/AWARDS/PRIZES

During FY 2011 I was made a fellow of the American Meterological Society and a fellow of the American Geophysical Union and was awarded the Sverdrup Gold Medal of the American Meterological Society.